DC Community Microgrid: Smart Affordable DC Electricity for an Underserved Inner City Community

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Low Voltage DC Microgrids

• Advantages
  – Eliminate the cost and extra losses of redundant AC-DC conversions
  – Lower Cost implementation of DER than AC microgrids
  – Lower installation, infrastructure and maintenance cost of new microgrids

• Opportunities
  – Green Buildings, Data Centers
  – Community Microgrid
  – Multiple Inter-connected Microgrids within a City

• Challenges
  – Lack of standards
  – Distribution and Protection!
LVDC Microgrid Value Proposition

- DC Microgrids will accelerate the adoption and insertion of power electronics into the electric grid by enabling effective utilization of energy saving loads and integration between renewable energy resources and storage
  - More efficient power delivery and more effective energy dispatch
  - *DC systems will be less complex and less expensive to deploy, operate and maintain.*
  - Growing “DC Backbone” of building and home loads (lighting, motors, electronics)
  - No need for phase synchronization
  - Plug and play power electronics enabled systems can be achieved
  - DC systems can be safer than AC
    - Control of ARC flash exposure can be realized
      $\Rightarrow$ *Faster Protection is a key element*

- Circuit protection can be faster and more reliable $\Rightarrow$ *New ideas for protective devices and distribution are needed!*
The “Smart Home” concept requires that a home be converted to DC distribution in order to enable:

- Efficient power delivery to growing number of DC loads
- Cost effective integration of renewable energy and energy storage
Low income households expend >14% on utilities compared to middle class households, which expend 3% of their income.

Utility costs are a major impediment to economic mobility—this fact is recently becoming recognized.

Adoption of cost saving/environmentally friendly technologies such as Solar PV plus batteries is out of reach of low income households—creates an ever widening disparity gap.

Proposed Solution: Interconnected smart homes with cooperative energy.
Distribution System Design—
Lead Home Garage (Sub-Station)

Feeds to CMG Homes:
Bi-directional Solid State Circuit Breakers (SSCBs)
Distribution System Design—Home

- **AC/DC System Interlock**
- **POL Converters for DC Loads**
- **DC Feeder Home: Bi-directional Solid SSCB**
- **Battery Management System (BMS)**

**Feed to Home:** Uni-directional SSCBs

**Feed from Home:**
- 240Vac Feed
- 380Vdc Feed
- 120Vac

**Interlock S}_{340-380Vdc}

- **Cloud**
- **Outlets**
- **Cloud**
- **Power over Ethernet**
- **High Speed Isolated Serial Interface**
- **Bidirectional SSCB with isolation circuitry**
- **Unidirectional SSCB with isolation circuitry**
- **Electromechanical circuit breaker**

- **240Vac Standard Residential AC Power Panel**
- **120Vac Clothes Washer Range**
- **380Vdc Emergency Battery Storage**
- **340-380Vdc Interlock**
- **30A 48Vdc Water Heater**
- **10A 24Vdc Clothes Dryer Freezer/Fridge**
- **10A 12Vdc LED Lights**
- **5A 12Vdc Home Gateway Outlets**
- **48Vdc Battery Storage**
- **48Vdc Smart Device Gateways**
- **48Vdc PoE Switch**
- **340-380Vdc from Hub Residence Garage**
- **PV Panels on Participant Residence Garage Roof**

**Center for Sustainable Electrical Energy Systems**
## AC vs. DC Home Load Break-Outs

<table>
<thead>
<tr>
<th>Load</th>
<th>AC Service Voltage</th>
<th>DC Service Voltage</th>
<th>AC Load Power Consumption (kW)</th>
<th>DC Load Power Consumption (kW)</th>
<th>Usage per Month (Hr)</th>
<th>AC Monthly KW-Hr</th>
<th>DC Monthly KW-Hr</th>
<th>AC Appliance Cost</th>
<th>DC Appliance Cost</th>
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<tbody>
<tr>
<td>A/C</td>
<td>230</td>
<td>360</td>
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<td>Water Heater</td>
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<td>72</td>
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<td>100</td>
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<td>Washer</td>
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<td>5</td>
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<td>13</td>
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<td>Microwave</td>
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<td>108</td>
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<td>$800.00</td>
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</tr>
</tbody>
</table>
AC vs. DC Home Solar/Battery Integration

AC wired home with installed solar panels

Proposed DC microgrid with mixed AC and DC wired home
What is the issue with DC Protection?

AC System: Zero crossing provides opportunity for electromechanical circuit breaker arc to extinguish. Upstream & downstream circuit breakers can coordinate because AC reactance limits currents.

DC System: No zero crossing, so electromechanical circuit breakers must be de-rated. Virtually impossible for upstream & downstream circuit breakers to coordinate due to current limitation of upstream source.
Circuit breaker needs to act within the first few microseconds
For Radial Systems: Need to distinguish between upstream and downstream faults in order isolate the fault to the closest location
For Ring Buses: High speed communications, high degree of sensing and embedded intelligence are required in order to isolate the fault to the closest location
DC System Circuit Breaker Coordination

The Fault is Characterized by the system capacitance and cable inductance, so the device must be able to act very quickly on the LC ring-up.

Fig. 1. Current and reaction time curves of traditional electromechanical circuit breakers, prior art SSCBs, and the proposed SSCB concept.
Impact of Wide Band Gap Devices on Protection

- Low conduction losses
- High commutation speed
- Devices suitable for HVDC but they are too costly right now
- The cost issue may be manageable for highly integrated MVDC systems (i.e. Navy shipboard)
- The current ratings are too low for MVDC (module paralleling is required)
- SiC and GaN JFET are attractive for LVDC
DC Circuit Breaker Solutions

Communications Based

Boost Rectifier

Autonomous

Normally On JFET
Normal “On” SiC JFET Based Approach

This concept will be tested, developed and evolved

Bi-Directional Implementation

- Suitable for 400V-1000V applications
- Level trip setting through a simple resistor adjustment
- Simple relay circuit for fault isolation
JFET Based Switch Implementation & Test

A simplified SSCB block diagram shown in a short circuit test setup

1200V, 45mΩ, normally-on SiC JFET as the main power switch

New 2-Terminal SSCB

Fast Starting Isolated DC/DC Converter

DC

Cap Bank

+-

 Normally-on SiC JFET

Current-Limiting Resistor (0.1-2Ω)

V_{GS}

SSCB responded in less than 1 μs

Measured waveforms of the SSCB’s short circuit current and control circuit output

Time Scale: 1 μs/div

Short Circuit Current: 50 A/div

V_{GS} Going from 0 to -20V (20 V/div)

Collaboration with Illinois Institute of Technology
Broader Vision

• Increase adoption of renewable energy among a greater population within the U.S. building upon concepts developed in India and Taiwan
• Protective concepts are applicable to DC buildings
• Enables viable DC system implementations → Commercialization of DC SSCB
• Leads to first embedded urban Community Microgrid—potential for significant social impact, addresses the educational impediment to adoption